

# Dark Sector Studies with Neutrino Beams

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Kevin J. Kelly, Fermilab

On behalf of the authors of [SNOWMASS21-NF3 NF0-RF6 RF0-CF1 CF3-TF9 TF11-148](#)

Contacts: Brian Batell, Joshua Berger, Yanou Cui, Valentina De Romeri, Wooyoung Jang, Kevin J. Kelly, Pedro A.N. Machado, Gianluca Petrillo, Yu-Dai Tsai, Yun-Tse Tsai, Jaehoon Yu

# Goal of this LOI

- ▶ Identify and classify the types of dark sector searches that can be studied in (accelerator) neutrino beam environments, like those built at J-PARC, Fermilab, etc.
- ▶ Focus on beam environments for some specificity, and to avoid overlap with, for instance, boosted dark matter searches from other sources, atmospheric production, and others.

Model	Production	Detection
Higgs Portal	$K, B$ decay	Decay ( $\ell^+ \ell^-$ )
Vector Portal	$\pi^0, \eta$ Decay	Scattering ( $\chi e^-, \chi X$ , Dark Tridents)
	Proton Bremsstrahlung	Decay ( $\ell^+ \ell^-, \pi^+ \pi^-$ )
	Drell-Yan	Inelastic Decay ( $\chi \rightarrow \chi' \ell^+ \ell^-$ )
Neutrino Portal	$\pi, K, D_{(s)}, B$ decay	Decay (many final states)
ALP Portal ( $\gamma$ -coupling dominant)	Meson Decay	Decay ( $\gamma\gamma$ )
	Photon Fusion	Inverse Primakoff process
	Primakoff Process	
Dark Neutrinos	SM Neutrino	Upscattering + Decay ( $\nu \rightarrow \nu_D, \nu_D \rightarrow \nu \ell^+ \ell^-$ )
Dipole Portal	Dalitz Decay	Decay ( $\nu_D \rightarrow \nu \gamma$ )
$\nu$ philic Mediators	SM Neutrino	Scattering (Missing $p_T$ , SM Tridents)

# Sampling of Detectors

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- ▶ Experiments that can search for many of these models (often simultaneously) – **not** an exhaustive list!

CHARM

MINOS

MINERvA

Nu-Cal

MiniBooNE(-DM)

T2K

T2HK

MicroBooNE

ICARUS

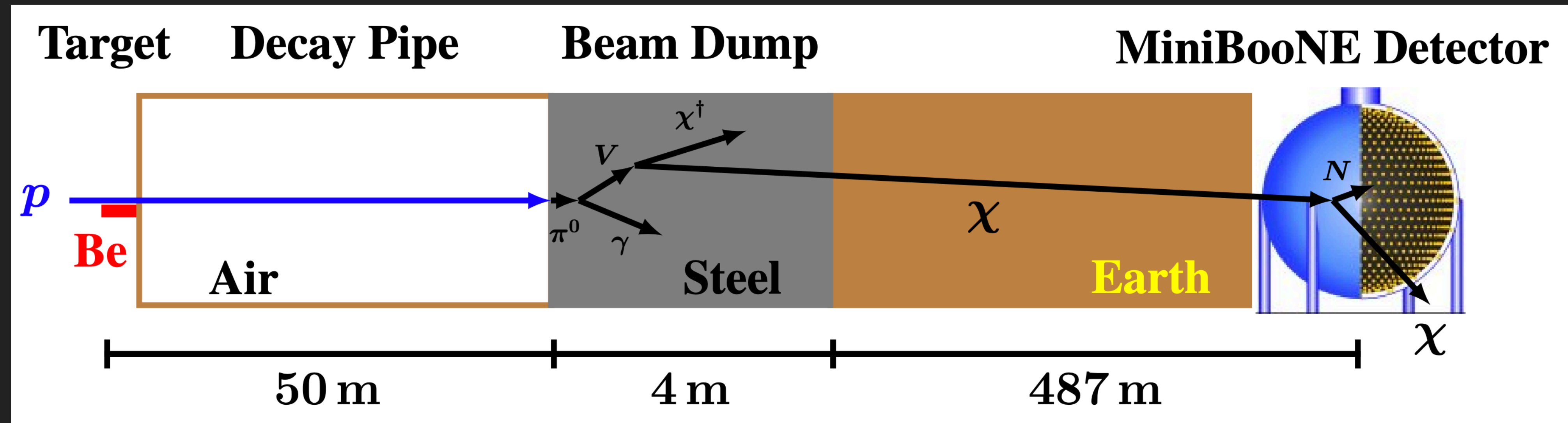
SBND

DUNE

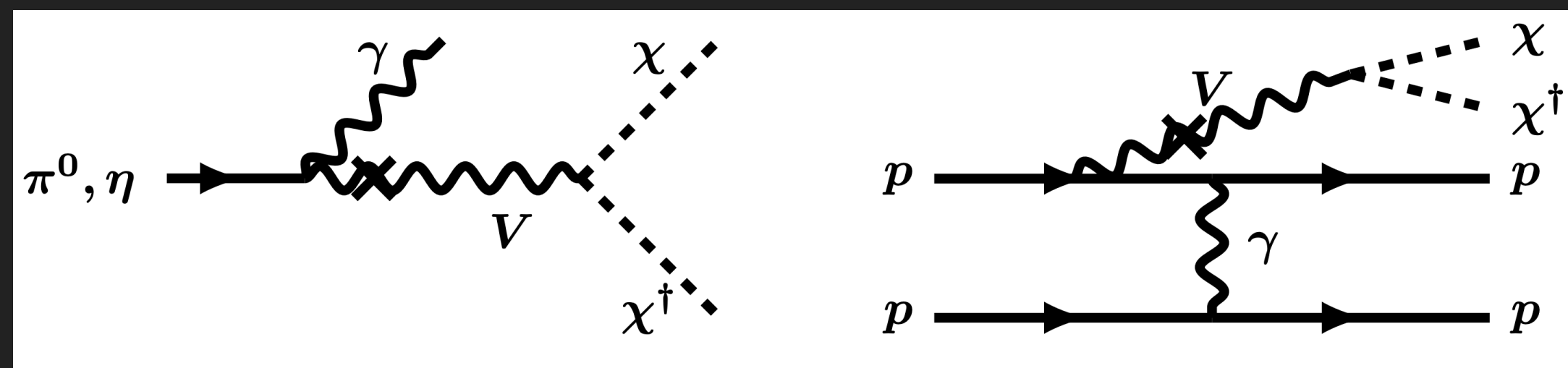
# Light Dark Matter at MiniBooNE

[1702.02688]

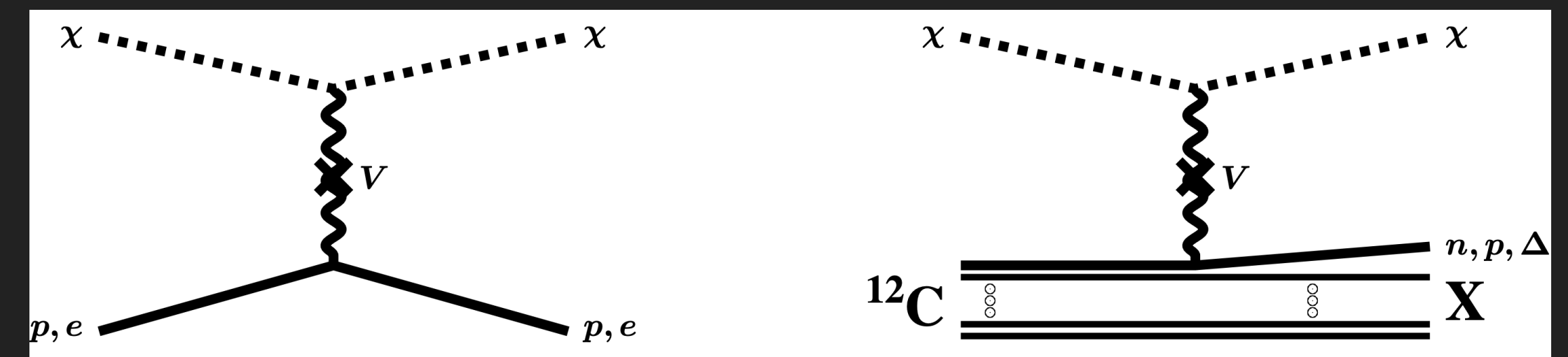
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- ▶ Dedicated beam dump run of MiniBooNE: DM can be produced via the decays of neutral pions or in bremsstrahlung and travel to MiniBooNE, where they can scatter off nucleons/electrons.
- ▶ Beam dump suppresses neutrino “background” significantly, allowing for incredible sensitivity.



DM Production



DM Scattering

Subset of theoretical work that inspired this: [0906.5614], [1107.4580], [1205.3499]

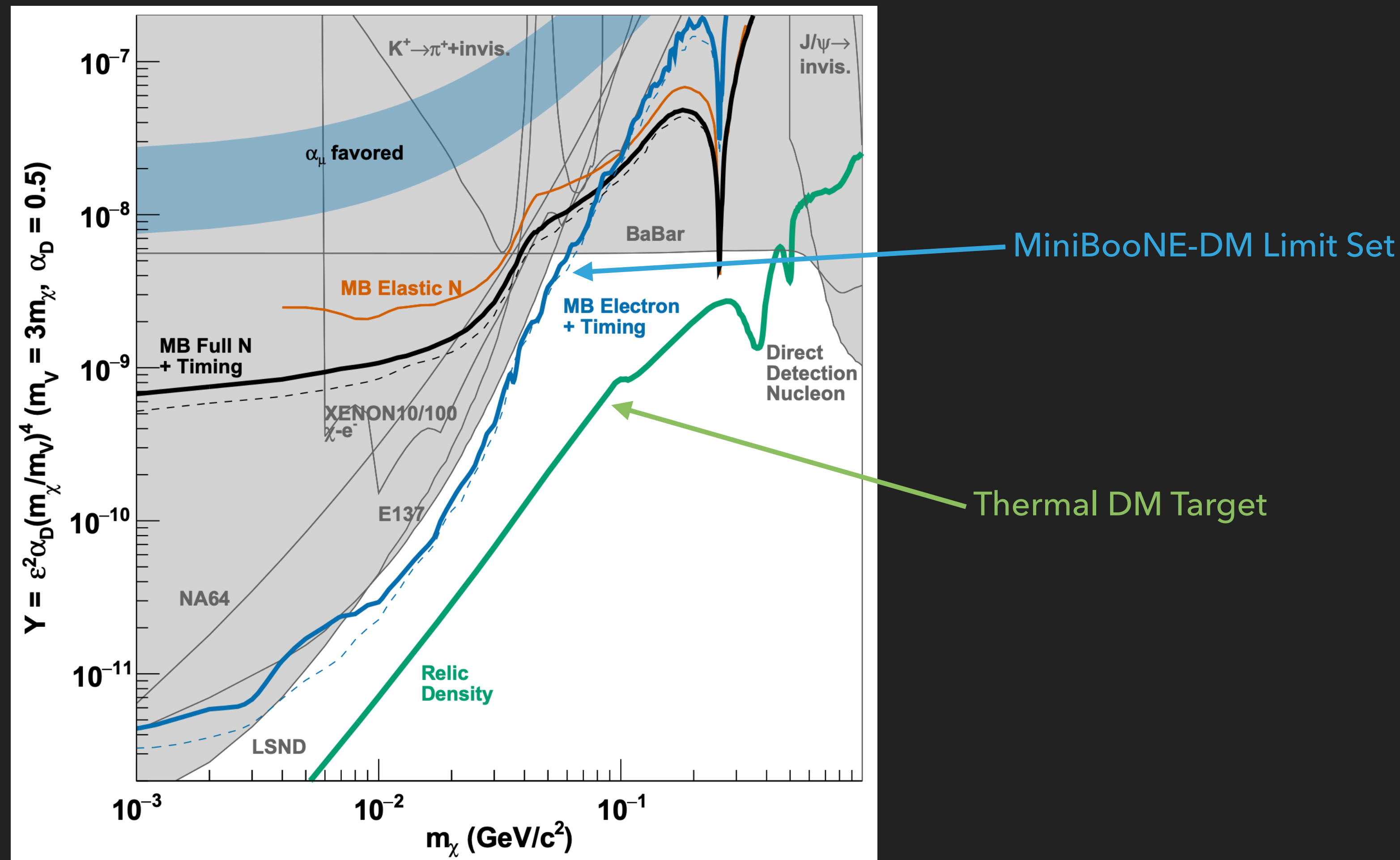


# Light Dark Matter at MiniBooNE

[1807.06137]

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- ▶ Beam Dump operation occurred in 2013/2014, with a total of  $1.86 \times 10^{20}$  Protons on Target.
- ▶ Because of the dedicated Beam Dump operation, the limit set on light dark matter is among the most powerful, and is difficult for next-generation experiments to surpass without their own beam dump plans.

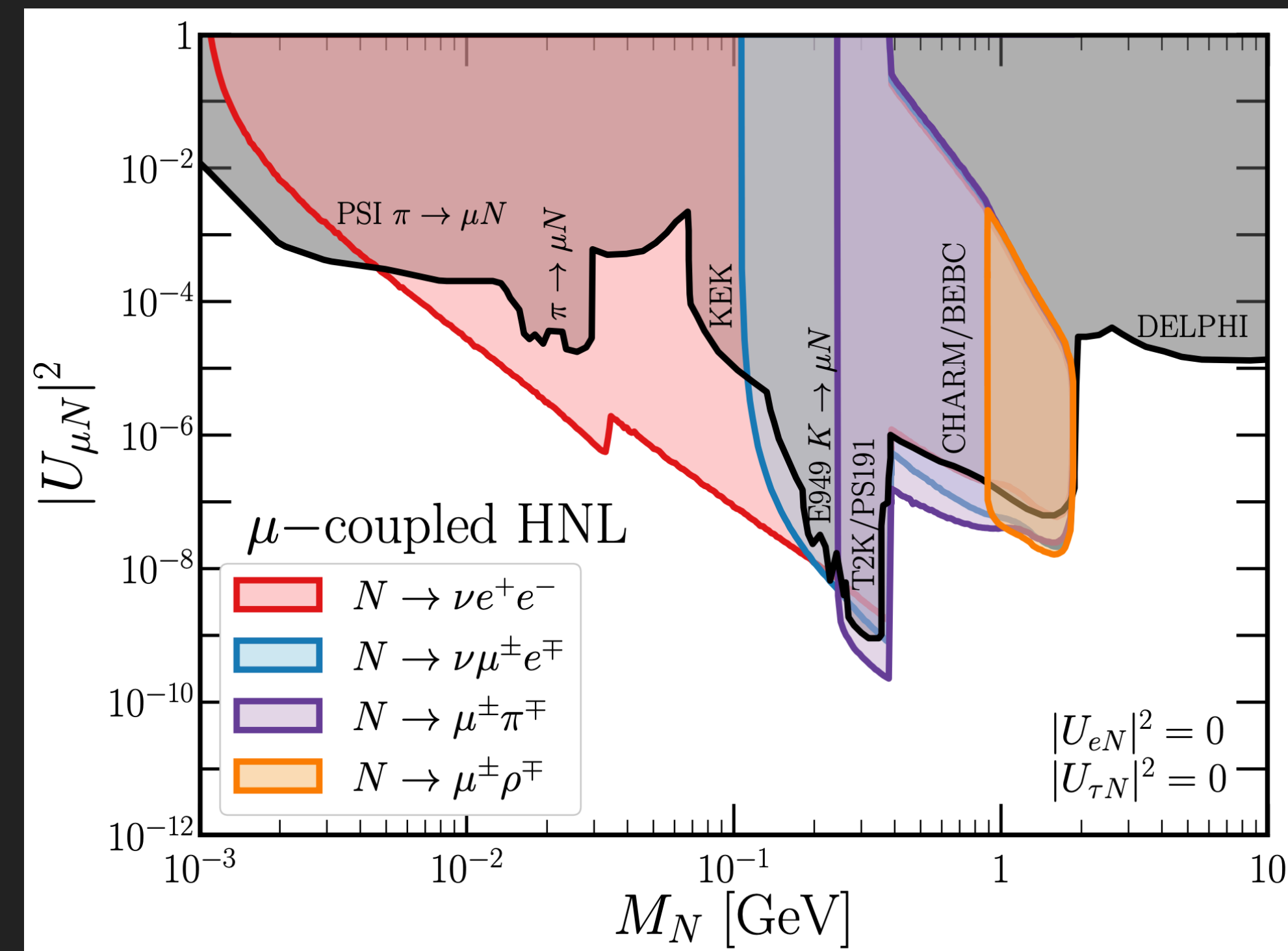
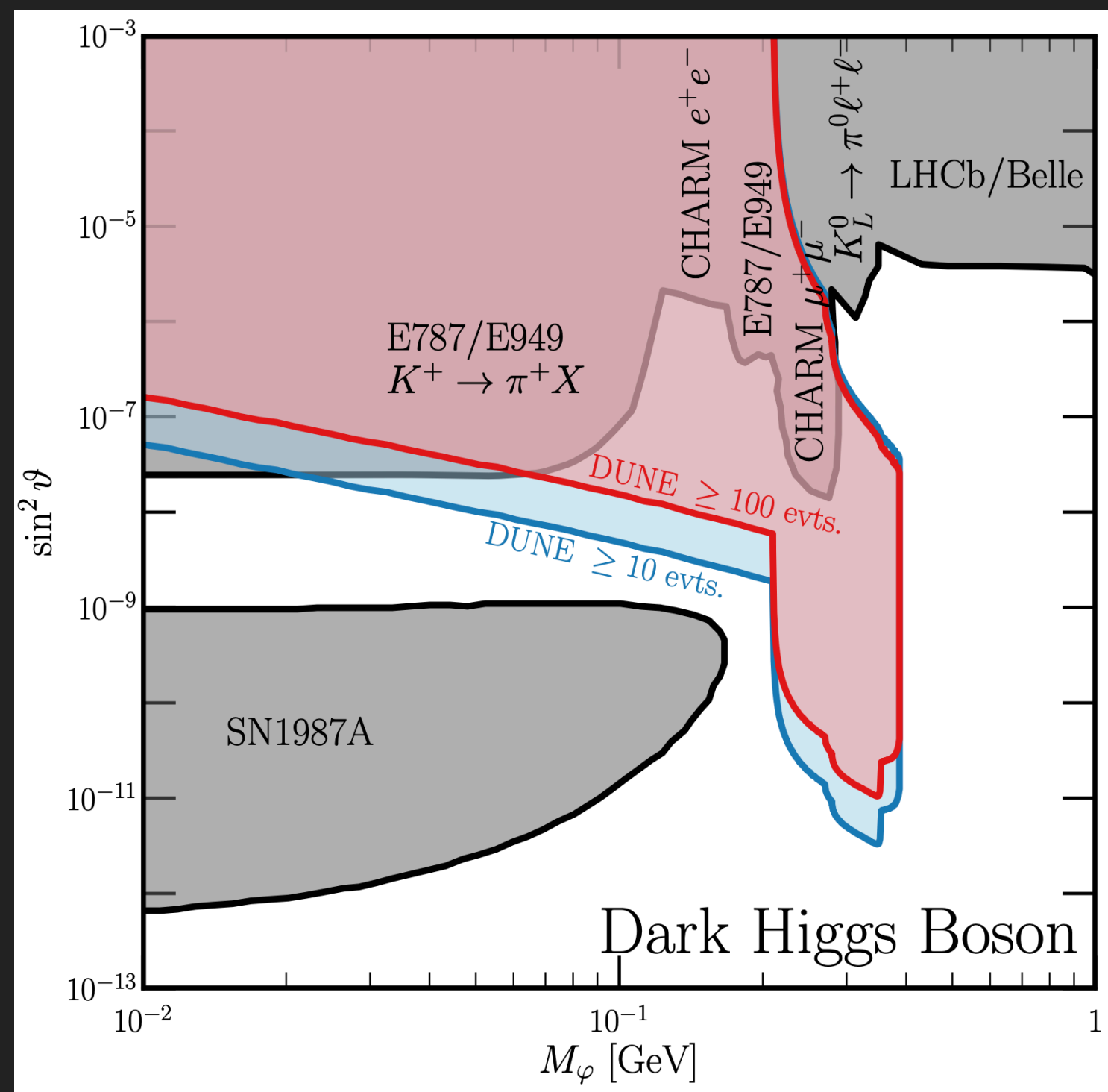
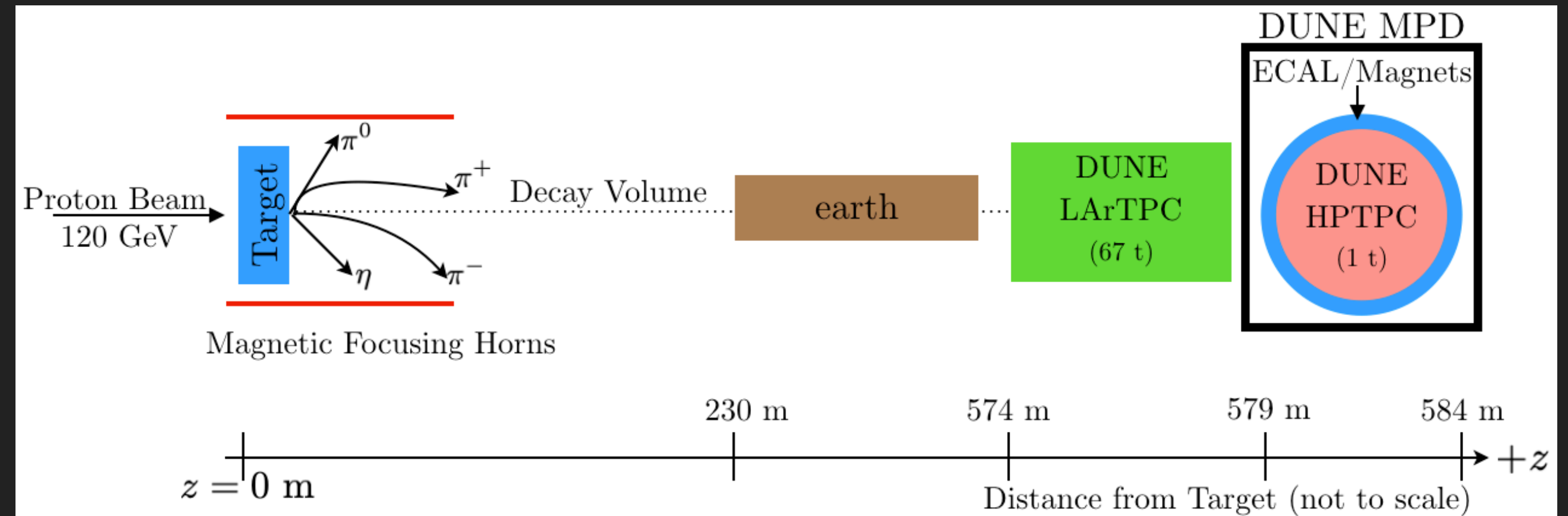


# Dark Mediator Decays in DUNE

[1912.07622]

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Symbiotic – can perform highly sensitive searches *during* neutrino beam operation. In fact, focusing of charged mesons can enhance sensitivity to some dark sector scenarios.



# Dark Sector Software/Tools

[1812.05616]

## A Module For Boosted Dark Matter Event Generation in GENIE

Joshua Berger

Models that produce a flux of semi-relativistic or relativistic boosted dark matter at large neutrino detectors are well-motivated extensions beyond the minimal weakly interacting massive particle (WIMP) paradigm. Current and upcoming liquid argon time projection chamber (LArTPC) based detectors will have improved sensitivity to such models, but also require improved theoretical modeling to better understand their signals and optimize their analyses. I present the first full Monte Carlo tool for boosted dark matter interacting with nuclei in the energy regime accessible to LArTPC detectors, including the Deep Underground Neutrino Experiment (DUNE). The code uses the nuclear and strong physics modeling of the GENIE neutrino Monte Carlo event generator with particle physics modeling for dark matter. The code will be available in GENIE v3. In addition, I present a code for generating a GENIE-compatible flux of boosted dark matter coming from the Sun that is released independently.

GENIE-based code for DM production and DM/SM interactions

BdNMC: [1609.01770]

Light dark matter in neutrino beams: production modelling and scattering signatures at MiniBooNE, T2K and SHiP

Patrick deNiverville,<sup>1</sup> Chien-Yi Chen,<sup>1,2</sup> Maxim Pospelov,<sup>1,2</sup> and Adam Ritz<sup>1</sup>

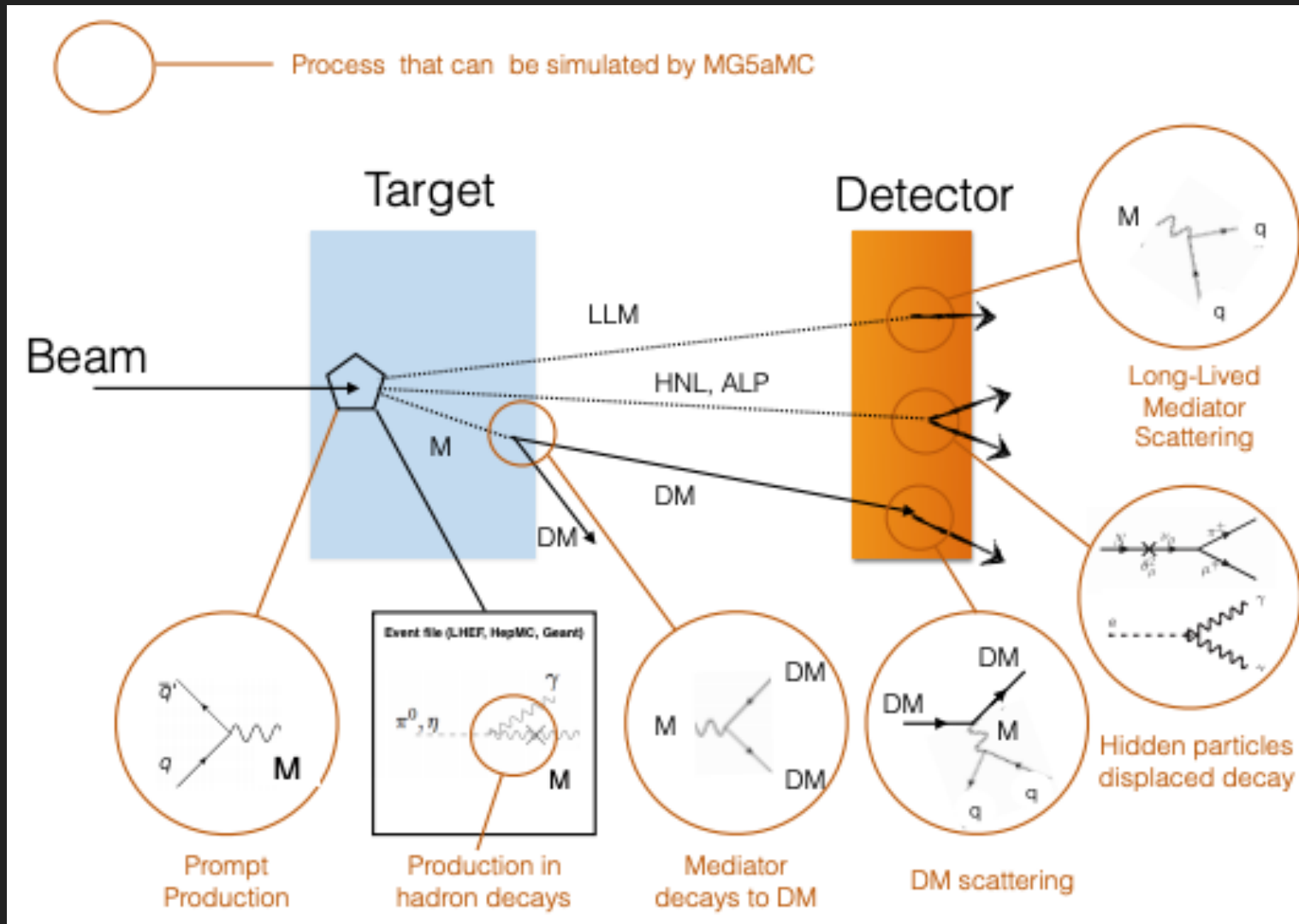
<sup>1</sup>Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 5C2, Canada

<sup>2</sup>Perimeter Institute for Theoretical Physics, Waterloo, ON N2J 2W9, Canada

(Dated: September 2016)

Independent code for DM production and scattering off nucleons/electrons

Code available on [github](https://github.com)



[1812.06771]

MG5aMC: MadGraph-based code for DM production and a variety of detector signatures.

By Luca Buonocore, Claudia Frugiuele, Fabio Maltoni, Olivier Mattelaer, Francesco Tramontano



# Conclusions

- ▶ Neutrino experiments combined with intense beams provide a mechanism to search for many interesting, well-motivated dark sector scenarios.
- ▶ Rich phenomenology between different production mechanisms (including using the neutrino beam itself), different scattering signatures, and different decay signatures.
- ▶ Searches can be performed in dedicated “beam dump” modes or simultaneously with neutrino beam operation – different benefits and disadvantages for each.

**Stay tuned for more. Thanks!**